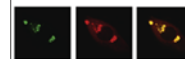


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Research Report

EEG changes caused by spontaneous facial self-touch may represent emotion regulating processes and working memory maintenance

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ABSTRACT

Spontaneous facial self-touch gestures (sFSTG) are performed manifold every day by every human being, primarily in stressful situations. These movements are not usually designed to communicate and are frequently accomplished with little or no awareness. The aim of the present study was to investigate whether sFSTG are associated with specific changes in the electrical brain activity that might indicate an involvement of regulatory emotional processes and working memory. Fourteen subjects performed a delayed memory task of complex haptic stimuli. The stimuli had to be explored and then remembered for a retention interval of 5 min. The retention interval was interrupted by unpleasant sounds from The International Affective Digitized Sounds and short sound-free periods. During the experiment a video stream of behavior, 19-channel EEG, and EMG (of forearm muscles) were recorded. Comparisons of the behavioral data and spectral power of different EEG frequency bands (theta, alpha, beta, and gamma) were conducted. An increase of sFSTG during the application of unpleasant sounds was observed. A significant increase of spectral theta and beta power was observed after exploration of the stimuli as well as after sFSTG in centro-parietal electrodes. The spectral theta power extremely decreased just before sFSTG during the retention interval. Contrary to this, no significant changes were detected in any of the frequencies when the spectral power before and after instructed facial self-touch movements (b-iFSTG and a-iFSTG) were compared. The changes of spectral theta power in the intervals before and after sFSTG in centro-parietal electrodes imply that sFSTG are associated with cortical regulatory processes in the domains of working memory and emotions.

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1. Introduction

Spontaneous self-touch gestures (sSTG) are spontaneous touching movements of the own body performed with one's own fingers and hands. In the process, nose, chin, cheek, head, thigh or other parts of the body are touched with the fingers for a short time. The term "spontaneous" means these kinds of movements, particularly the triggering of the movements, is not based on deliberate decision-making processes of the respecting person. Contrary to other self-touching actions in experimental settings (Ackerley et al., 2012; Guest et al., 2009; Schutz-Bosbach et al., 2009; van Stralen et al., 2011; White et al., 2010) spontaneous STG are performed without a request by any other person and without any prompt by an external stimulus. These spontaneous movements are fairly common in everyday life and may be observed as a ubiquitous behaviour in people from all social classes. In contrast, precise psychological and neurobiological understanding and knowledge of this spontaneous behavior is vanishingly low. Several scientific disciplines have tried to empirically describe the phenomenon and to explain its function. First systematic descriptions and interpretations of sSTG have been made in the field of nonverbal behaviour regarding speech production and interpersonal communication. In this context Harrigan et al. distinguished sSTG from gestures which are related to speech content or rhythm and from instrumental acts. Spontaneous self-touch gestures are not usually designed to communicate and are frequently accomplished with little or no awareness (Harrigan et al., 1987). Such sSTG appear both during human interactive behavior and in situations when people are alone. According to Harrigan, 55% of sSTG are applied to head or face, 8% are applied to the legs and 2% of sSTG are directed to the trunk.

In some studies an association between sSTG frequency and social status was found during dyadic and group discussions. Individuals with low social status showed more sSTG than individuals with higher social standing (Carney et al., 2005; Hall et al., 2001, 2005; Harrigan et al., 1991).

Also, the influence of visual and acoustic stimuli on the occurrence of sSTG has been studied. Butzen et al. (2005) observed a significant increase of sSTG in test subjects who were watching a video about chiggers (sand fleas).

In a study from Heaven et al. the participants were listening to texts about leeches and about canaries. After the listening period the participants had to answer several questions. The authors did not find any differences in sSTG between the two listening conditions but an increase in sSTG during the answering period compared to the listening period. In that study, significant sex differences were also found: added together, men performed significantly more sSTG than women (Heaven and McBrayer, 2000).

To further investigate the sex effect Heaven et al. 2002 analyzed whether the frequency of sSTG differed in men and women while reading about leeches and canaries and during a subsequent discussion about the texts. While the authors were not able to verify the previously found sex effect, the results did show a significant increase of sSTG during the discussion as compared to reading (Heaven et al., 2002).

Knöfler and Imhof also reported that men showed more sSTG than women during interpersonal communication. Furthermore, the authors found that heterosexual individuals performed more sSTG during interpersonal communication with homosexual individuals (Knöfler and Imhof, 2007).

Kimura showed that dominant right hander's performed sSTG equally often with the left and the right hand (Kimura, 1973a, 1973b). However, persons with strong field dependence showed a strong asymmetry of sSTG to the left hand (Sousapoza et al., 1979).

Self-touch gestures have not only been observed in adults but also in children. D'Alessio and Zazzetta studied the occurrence of self-touch in children (2 years and 8 months to 5 years and 10 months old) during unrestrained play. They reported that the frequency of self-touch was higher in younger children and that there was a trend towards girls showing more self-touch gestures than boys. Girls directed significantly more sSTG to their head and hands, while boys showed a preference for their trunk and feet (D'Alessio and Zazzetta, 1986). In a study by Rögels et al. (1990) children between 3 and 6 years showed more self-touch gestures while talking about a cartoon they had just seen than while watching the cartoon.

Barroso and Feld investigated the occurrence of unilateral (one handed self-touch gestures) and bilateral (both hands move simultaneously) self-touch gestures as a function of four different auditory attention tasks of varying complexity. They found that with increasing complexity and attentional demands both uni- and bilateral self-touch gestures increased. In this case, women performed significantly more unilateral self-touch gestures than men. For bilateral gestures, however, no sex effect was found (Barroso and Feld, 1986).

Moreover, sSTG have been studied in primates (termed 'self-directed-behavior'). Studies of humans and primates have shown that the number of sSTG increases during stressful and fearful situations (Butzen et al., 2005; Heaven and McBrayer, 2000; Maestripieri et al., 1992). In line with this, the administration of anxiolytic drugs reduced the number of sSTG in primates (Schino et al., 1991; Troisi et al., 1991).

So far, the bio-psychological functions of sSTG have been discussed on the basis of behavioral data only. For example, Ekman and Friesen speculated that sSTG support the organization of sensory input necessary for the regulation of emotion and are involved in the regulation of speech processes (Ekman and Friesen, 1969a, 1969b, 1972; Harrigan et al., 1987). They hypothesized that self-touching is an attempt to cope with unpleasant affect. Similarly, Freedman hypothesized that sSTG are primarily generated by persons who exhibit minor hemispheric speech dominance and that these persons reduce emotional stress by means of sSTG (Freedman et al., 1973; Freedman and Hoffman, 1967). Scherer and Wallbott hypothesized that a U-relationship might exist between the frequency of sSTG and arousal. Accordingly, sSTG may occur more often during low arousal to increase it and during high arousal to evoke a down-regulation of arousal. During medium arousal they occur less frequently (Scherer and Wallbott, 1979).

Taken together, these theories and hypotheses suggest that sSTG are relevant for the regulation of emotional and

cognitive processes. Prior results suggest that sSTG arise when information occur which are irrelevant to a task and which have a negative emotional load. These information then interfere with the emotional status and cognitive processes that are relevant to a task. Particularly working memory processes may be vulnerable as previous studies have shown that positive as well as negative emotional information interfere with working memory performance (Kuhlmann et al., 2005; Osaka et al., 2013).

Accordingly, if a cognitive task poses a high demand on working memory, the occurrence of stimuli that are irrelevant to the task and associated with negative emotions should interfere with the maintenance and encoding of information and consequently trigger sSTG.

To verify this hypothesis psycho-physiological indicators are necessary that represent (a) working memory processes and (b) emotional processes in the scope of a specific task. Additionally, these parameters should also show which biopsychological changes occur due to the sSTG. This may be accomplished for example with the help of pre post comparisons. Since sSTG happen very fast and the possible psycho-physiological changes would also take place quickly, the measured parameters need to have a high temporal resolution—like the electrical activity of the brain. However, no electrophysiological or imaging studies of the topic exist so far. Such data might generate results in favor of the hypothesis that sSTG serve a regulatory function by showing significant neurophysiological changes after sSTG as compared to before. Therefore, the aim of this pilot study was to examine the electro cortical activity before and after sSTG in an experimental setting. Previous studies have shown that sSTG most often consist of touching movements of the head and face. Therefore, we investigated the electrical brain activity immediately before and after spontaneous facial self-touch gestures (sFSTG). Given the above mentioned speculations about sFSTG as a regulatory process of emotion and working memory, we expect clear differences in the EEG power of periods immediately before as compared to immediately after sFSTG. These assumed EEG changes should occur only with facial self-touch that was performed spontaneously but not with facial self-touch gestures that were prompted by the experimenter.

To test this hypothesis EEG parameters should be analyzed that are sensitive to changes in emotional and working memory processes. However, the human electrical brain activity from different emotional and cognitive processes may be described by many single electrical components and single frequencies. Since no electrophysiological data exists so far concerning the present topic and hypotheses, we tried to choose suitable spectral EEG parameters based on the following EEG studies.

Changes of emotional states and corresponding spectral EEG changes have been studied extensively. Especially the frontal theta frequency has been shown to be sensitive to emotional processes (Aftanas and Golosheykin, 2005; Aftanas et al., 2001; Bekkedal et al., 2011; Craig et al., 2012; Debus et al., 1994; Harrigan et al., 1987; Knyazev et al., 2012; Pizzagalli, 2005; Rusalova and Kostyunina, 2003; Sammler et al., 2007).

Analyses of cognitive processes (especially working memory processes) have also shown that the theta frequency

reflects changes and dynamics across different modalities and tasks (Bastiaansen and Hagoort, 2003; Grunwald et al., 1999; Grunwald et al., 2001b; Jensen and Tesche, 2002; Michels et al., 2012; Mitchell et al., 2008; Palomaki et al., 2012; Raghavachari et al., 2001; Rawle et al., 2012; Rietschel et al., 2012; Seemuller et al., 2012; Tesche and Karhu, 2000; Toth et al., 2012; White et al., 2012). Consistently, these studies reported decreases in theta activity to be associated with low working memory load while increases in theta power seemed to be related to high working memory load.

Therefore, we expect to find changes in the theta frequency that accompany changes of emotional states and working memory load. If spontaneous self-touch gestures have regulating functions then significant differences should be observable in the theta band before and after self-touch. Low emotional stability and simultaneous loss of working memory load should be marked by low theta power immediately before facial self-touch. If spontaneous self-touch initiates a stabilization of emotional and working memory load this should be reflected by an increase in theta power in the period after self touch.

Additionally, we expect to find differences of central beta power due to motor processes before and after spontaneous self touch as well as before and after instructed facial self-touch (Klostermann et al., 2007; Serrien et al., 2006; Tzagarakis et al., 2010). On the other hand, we expect to find no changes in theta power when the facial self-touch gestures are performed due to the explicit request of the experimenter (instructed FSTG).

Since, at this point, no specific hypotheses can be deduced for alpha and gamma frequencies, the changes of these EEG parameters will be presented with exploratory analyses only.

To observe and analyze respective EEG changes before and after spontaneous self-touch it is necessary to take the dynamic EEG changes of the whole experimental situation into account. The specific EEG dynamics before and after spontaneous self-touch, can only be determined in relation to the whole experimental situation. To account for this, we chose an established experimental setting during which EEG changes due to working memory load have been observed before (Grunwald et al., 1999, 2001b) and added auditory stimuli with a negative emotional load during the retention interval.

2. Results

As expected, the subjects showed significantly more sFSTG during the retention interval (sum=71) than during haptic exploration (sum=28) and the reproduction period (sum=35) (Friedmann non-parametric test for dependent groups, $p=.011$). During the retention interval (RI) $M=5.07$, $SD=3.70$) sFSTG were performed by the subjects.

Comparisons of the EEG of the resting period (baseline) and after haptic exploration (aHE) showed significant increases of the spectral power of all frequency bands except for alpha. Theta power increased mainly above central-parietal regions. Beta increased above central-parietal and occipital regions. Increases of the gamma band were

observed over the whole cortex except for right-frontal (Fp2, F4), left-temporal (T3) and Fz electrodes (see Table 1a).

The comparison of the spectral power after haptic exploration (aHE) and before spontaneous facial self-touch (b-sFSTG; during the retention interval) showed a distinct decrease in theta and gamma power before sFSTG. In both bands the changes occurred predominantly in central-parietal and occipital regions. The changes in beta showed merely a marginal difference between the experimental periods that did not

reach the critical alpha level (Table 1b). The spectral power of the alpha frequency did not show any significant changes.

On the other hand, except for F7 of the gamma band no significant differences in any of the frequency bands were detected when the spectral power after haptic exploration (aHE) and after spontaneous facial self-touch (a-sFSTG) were compared (Table 2a).

In accordance with the above, statistical comparisons of the spectral power before and after spontaneous facial

Table 1a – Spectral EEG power comparisons between rest and after haptic exploration (aHE).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	Z	p	z	p	z	p	z	p
FP1	-.663	.508	-.764	.445	-1.580	.114	-2.599	.009
FP2	-2.395	.017	-1.478	.139	-1.784	.074	-1.478	.139
F3	-1.376	.169	-.357	.721	-1.988	.047	-2.497	.013
F4	-1.274	.203	-1.172	.241	-.764	.445	-.764	.445
C3	-2.191	.028	-.561	.575	-2.701	.007	-2.701	.007
C4	-1.682	.093	-.764	.445	-1.784	.074	-2.599	.009
P3	-2.191	.028	-.153	.878	-2.701	.007	-2.701	.007
P4	-1.886	.059	-.459	.646	-1.784	.074	-2.599	.009
O1	-1.886	.059	-.255	.799	-2.701	.007	-2.701	.007
O2	-1.886	.059	-.051	.959	-2.599	.009	-2.701	.007
F7	-.255	.799	-1.070	.285	-2.090	.037	-1.988	.047
F8	-2.599	.009	-1.274	.203	-2.497	.013	-2.803	.005
T3	-2.090	.037	-1.580	.114	-1.784	.074	-.764	.445
T4	-1.784	.074	-.357	.721	-1.478	.139	-2.293	.022
T5	-1.886	.059	-.051	.959	-2.803	.005	-2.803	.005
T6	-1.682	.093	-.153	.878	-2.497	.013	-2.701	.007
FZ	-.866	.386	-.051	.959	-.459	.646	-1.478	.139
CZ	-1.376	.169	-.459	.646	-1.988	.047	-2.293	.022
PZ	-1.886	.059	-.153	.878	-2.395	.017	-2.395	.017

Results of non-parametric Wilcoxon-tests per channel and frequency band.

Table 1b – Spectral EEG power comparisons between after haptic exploration (aHE) and before spontaneous self touch movements (b-sFSTG).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	Z	p	z	p	z	p	z	p
FP1	-.561	.575	-.255	.799	-1.682	.093	-1.478	.139
FP2	-.866	.386	-.255	.799	-2.497	.013	-1.886	.059
F3	-1.784	.074	-1.172	.241	-1.274	.203	-1.784	.074
F4	-2.395	.017	-1.376	.169	-1.580	.114	-.153	.878
C3	-2.599	.009	-1.172	.241	-1.988	.047	-2.803	.005
C4	-2.395	.017	-1.070	.285	-1.886	.059	-1.580	.114
P3	-2.803	.005	-1.172	.241	-2.497	.013	-2.395	.017
P4	-2.599	.009	-1.274	.203	-1.580	.114	-1.682	.093
O1	-2.090	.037	-.866	.386	-1.784	.074	-2.701	.007
O2	-2.090	.037	-1.478	.139	-2.293	.022	-2.293	.022
F7	-1.274	.203	-1.376	.169	-1.988	.047	-1.784	.074
F8	-1.886	.059	-.663	.508	-1.376	.169	-1.784	.074
T3	-1.886	.059	-1.886	.059	-1.580	.114	-.255	.799
T4	-1.886	.059	-.561	.575	-2.497	.013	-.255	.799
T5	-2.599	.009	-.968	.333	-2.191	.028	-2.191	.028
T6	-2.701	.007	-.968	.333	-1.988	.047	-2.191	.028
FZ	-1.682	.093	-.459	.646	-1.274	.203	-1.274	.203
CZ	-1.784	.074	-1.376	.169	-2.293	.022	-1.580	.114
PZ	-2.599	.009	-1.070	.285	-2.293	.022	-1.784	.074

Results of non parametric Wilcoxon-tests per channel and frequency band.

Table 2a – Spectral EEG power comparisons between after haptic exploration (aHE) and after spontaneous self touch movements (a-sFSTG).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	z	p	z	p	z	p	z	p
FP1	-.764	.445	-.663	.508	-1.784	.074	-1.376	.169
FP2	-1.580	.114	-1.172	.241	-1.172	.241	-.663	.508
F3	-1.784	.074	-.051	.959	-.561	.575	-1.070	.285
F4	-.968	.333	-.255	.799	-.051	.959	-.255	.799
C3	-1.886	.059	-1.274	.203	-1.376	.169	-2.191	.028
C4	-.663	.508	-1.172	.241	-.357	.721	-.561	.575
P3	-1.172	.241	-.153	.878	-1.784	.074	-2.191	.028
P4	-1.376	.169	-1.070	.285	-.663	.508	-.051	.959
O1	-1.478	.139	-.357	.721	-1.988	.047	-1.580	.114
O2	-1.172	.241	-.866	.386	-1.070	.285	-1.478	.139
F7	-.866	.386	-.866	.386	-2.497	.013	-2.701	.007
F8	-1.172	.241	-.764	.445	-.866	.386	-1.682	.093
T3	-1.580	.114	-.968	.333	-2.293	.022	-1.682	.093
T4	-.459	.646	-.561	.575	-1.070	.285	-1.580	.114
T5	-2.090	.037	-.153	.878	-2.191	.028	-1.172	.241
T6	-2.293	.022	-.663	.508	-.764	.445	-1.784	.074
FZ	-.561	.575	-1.784	.074	-.561	.575	-.357	.721
CZ	-.968	.333	-.968	.333	-.459	.646	-.357	.721
PZ	-1.886	.059	-.561	.575	-1.580	.114	-.357	.721

Table 2b – Spectral EEG power comparisons between b-sFSTG and a-sFSTG (before spontaneous self touch movements and after spontaneous self touch).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	Z	p	z	p	z	p	z	p
Fp1	-.561	.575	-.663	.508	-1.478	.139	-.255	.799
Fp2	-.459	.646	-.051	.959	-1.478	.139	-1.172	.241
F3	-.663	.508	-.357	.721	-1.886	.059	-.968	.333
F4	-2.497	.013	-1.274	.203	-2.497	.013	-1.274	.203
C3	-2.191	.028	-1.580	.114	-1.682	.093	-2.497	.013
C4	-2.497	.013	-.968	.333	-2.803	.005	-1.580	.114
P3	-2.701	.007	-1.274	.203	-1.784	.074	-2.191	.028
P4	-2.090	.037	-1.172	.241	-1.070	.285	-1.070	.285
O1	-2.293	.022	-.357	.721	-.968	.333	-.968	.333
O2	-1.988	.047	-1.376	.169	-1.376	.169	-1.376	.169
F7	-.357	.721	-.051	.959	-1.478	.139	-.968	.333
F8	-2.293	.022	-1.274	.203	-.153	.878	-.968	.333
T3	-1.478	.139	-1.274	.203	-.459	.646	-.051	.959
T4	-1.784	.074	-1.172	.241	-2.293	.022	-.561	.575
T5	-2.191	.028	-.968	.333	-1.070	.285	-1.274	.203
T6	-1.988	.047	-.866	.386	-1.070	.285	-1.274	.203
Fz	-1.886	.059	-.764	.445	-1.988	.047	-1.784	.074
Cz	-1.988	.047	-1.172	.241	-2.497	.013	-1.784	.074
Pz	-2.293	.022	-.561	.575	-1.376	.169	-1.070	.285

self-touch (b-sFSTG, a-sFSTG) showed significant changes of the theta frequency. These changes occurred above the central, parietal and occipital lobe. Changes in beta occurred above right-central areas. Both theta and beta power were higher after spontaneous facial self-touch movements than beforehand. In both alpha and gamma no significant changes could be detected. The results of the statistical comparisons between b-sFSTG and a-sFSTG per channel and frequency band are displayed in [Table 2b](#).

Contrary to this, no significant changes were detected in any of the frequencies when the spectral power before and after instructed facial self-touch movements (b-iFSTG and a-iFSTG) were compared (see [Table 3a](#)).

The comparison of the periods after sFSTG and eRI (end of the retention interval) did not show any significant differences in any of the frequencies ([Table 3b](#)). Likewise, no significant differences between the spectral power of eRI and aHE were detected.

Table 3a – Spectral EEG power comparisons between b-iFSTG and a-iFSTG (before instructed facial self touch movements and after instructed facial self touch movements).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	Z	p	z	p	z	p	z	p
Fp1	-.561	.575	-.459	.646	-1.274	.203	-.051	.959
Fp2	-1.682	.093	-1.886	.059	-.153	.878	-.968	.333
F3	-.663	.508	-.255	.799	-1.070	.285	-1.988	.047
F4	-.255	.799	-.459	.646	-.663	.508	-.255	.799
C3	-.561	.575	-.357	.721	-.968	.333	-.968	.333
C4	-.561	.575	-.459	.646	-.663	.508	-.357	.721
P3	-.255	.799	-.459	.646	-1.376	.169	-.764	.445
P4	-.051	.959	-.153	.878	-.459	.646	-.153	.878
O1	-.459	.646	-1.274	.203	-.866	.386	-1.070	.285
O2	-.764	.445	-1.172	.241	-.561	.575	-.968	.333
F7	-1.274	.203	-2.090	.037	-1.886	.059	-2.090	.037
F8	-.968	.333	-.255	.799	-.866	.386	-1.886	.059
T3	-.866	.386	-2.293	.022	-1.682	.093	-.866	.386
T4	-.357	.721	-1.682	.093	-.866	.386	-.459	.646
T5	-.255	.799	-1.274	.203	-.764	.445	-.663	.508
T6	-.561	.575	-.357	.721	-1.886	.059	-.051	.959
Fz	-.357	.721	-.663	.508	-.051	.959	-.051	.959
Cz	-.357	.721	-.153	.878	-.357	.721	-1.172	.241
Pz	-.459	.646	-.357	.721	-.764	.445	-1.070	.285

Table 3b – Spectral EEG power comparisons between a-sFSTG and eRI (after spontaneous self touch and end of the retention interval).

EEG electrodes	Theta		Alpha		Beta		Gamma	
	Z	p	z	p	z	p	z	p
FP1	-.561	.575	-.153	.878	-.153	.878	-.764	.445
FP2	-.968	.333	-.459	.646	-.255	.799	-1.172	.241
F3	-.561	.575	-.255	.799	-.051	.959	-.357	.721
F4	-1.580	.114	-1.988	.047	-1.988	.047	-1.376	.169
C3	-.764	.445	-.663	.508	-.561	.575	-1.988	.047
C4	-.663	.508	-.764	.445	-.153	.878	-1.682	.093
P3	-1.376	.169	-.357	.721	-1.376	.169	-1.580	.114
P4	-.764	.445	-.051	.959	-1.886	.059	-1.478	.139
O1	-.561	.575	-.968	.333	-1.274	.203	-.968	.333
O2	-.153	.878	-1.070	.285	-.764	.445	-.866	.386
F7	-.764	.445	-.051	.959	-.357	.721	-.866	.386
F8	-.051	.959	-.255	.799	-.866	.386	-.663	.508
T3	-.561	.575	-.459	.646	-.968	.333	-.866	.386
T4	-.051	.959	-.866	.386	-.255	.799	-.561	.575
T5	-.153	.878	-.663	.508	-1.172	.241	-.051	.959
T6	-.153	.878	-.561	.575	-.663	.508	-.051	.959
FZ	-.663	.508	-1.274	.203	-.764	.445	-1.682	.093
CZ	-.357	.721	-1.376	.169	-.051	.959	-1.784	.074
PZ	-.764	.445	-.051	.959	-1.478	.139	-1.682	.093

The mean spectral power maps of all frequencies before and after spontaneous FSTG and instructed FSTG are displayed in Fig. 1.

Within the framework of the experiment the strongest EEG changes occurred above central and parietal brain regions. Exemplary for the predominant EEG changes during the various experimental periods (baseline, aHE, b-sFSTG, a-sFSTG, eRI) Fig. 2 depicts the mean spectral power (box plots) of the electrodes P3, Pz and P4.

3. Discussion

The data for the present study were gathered in an experiment investigating EEG changes before and after spontaneous facial self-touch gestures (sFSTG) during a delayed memory task of complex haptic stimuli (sunken reliefs). The haptic stimuli had to be explored and subsequently remembered for a retention interval of 5 min. The retention interval

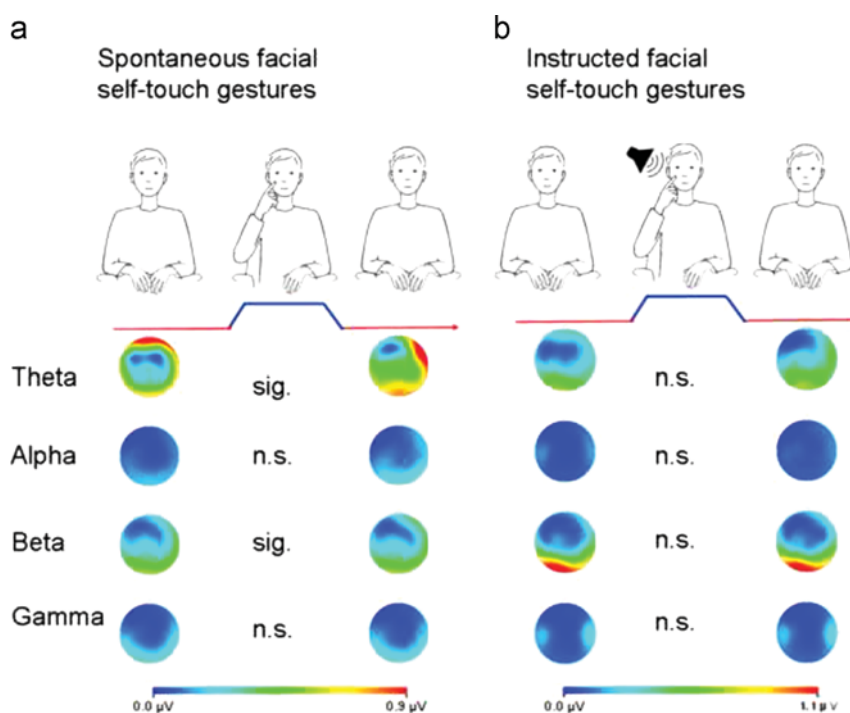


Fig. 1 – Mean spectral power map of theta, alpha, beta and gamma (μV^2) activities before and after spontaneous facial self-touch gestures (a) and instructed FSTG (b).

was accompanied by unpleasant sounds from the database of International Affective Digitized Sounds and short sound-free periods. During the retention interval we observed a dramatic increase of sFSTG. The experimental setting was designed as an emotionally and cognitively straining condition for the test subjects, as previous research concerning self-touch has shown a link between strain and self-touch.

In a condensed form the following changes in EEG were observed: An increase in spectral power was observed after the haptic exploration task. However, consistently just seconds before each facial self-touch (during the retention interval), an extreme decrease (below baseline) of the spectral power occurred. After self-touch the spectral power returned to the same level as where it had been after haptic exploration. In the following sections these changes will be discussed elaborately.

3.1. Comparison of baseline and after haptic exploration

The comparisons of the frequency bands (theta: 4.0–8.0, alpha: 8.0–13.0, beta: 13.0–24.0; gamma: 24.0–49.0 Hz) of the periods rest (baseline) and after haptic exploration (aHE) showed changes in spectral power after haptic exploration. While no differences were found in the alpha band, all the other frequencies (beta, theta and gamma) increased after haptic exploration. We interpreted the increase in spectral theta power as a result of high memory load due to the haptic exploration and memory task (perception and storage of haptic information). Our own previous research showed a relationship between the complexity of haptic stimuli and the amount of spectral theta power. That is, compared to a resting period, the theta power increased with the complexity of the stimuli (Grunwald et al., 1999, 2001b). The increase of

beta power after haptic exploration might represent post-movement beta synchronization (Klostermann et al., 2007; Serrien et al., 2006; Tzagarakis et al., 2010). It may also represent organization processes of larger neuronal networks (Buzsaki and Draguhn, 2004), i.e. to maintain the requested information.

The increase in spectral gamma power after haptic exploration may be interpreted as phase-coupling processes between theta and gamma oscillations. These may be due to top-down regulatory processes to maintain memory. Several previous studies have shown phase coupling between theta and gamma band oscillations during memory tasks (Basar and Karakas, 2000; Burgess and Ali, 2002; Demiralp et al., 2007; Doesburg et al., 2005; Schack et al., 2002; Schack and Klimesch, 2002; Simos et al., 2002; von Stein and Sarnthein, 2000). Doesburg et al. (2005) assumed that gamma oscillations represent mechanisms of information integration across different brain areas and that they are a neural correlate of consciousness.

3.2. Comparison of after haptic exploration and before spontaneous facial self-touch

The comparison of the spectral power of the experimental phases aHE and 3 s before spontaneous facial self-touch (b-sFSTG) showed that the theta and gamma power of b-sFSTG are significantly lower than after haptic exploration. That means, ultimately before the facial self-touch movements (during the retention interval), extreme decreases occurred of the spectral power of both theta and gamma. These occurred primarily in centro-parietal regions. At this point, what kind of internal processes led to these decreases in spectral power is open to speculation. One potential conjecture is that the

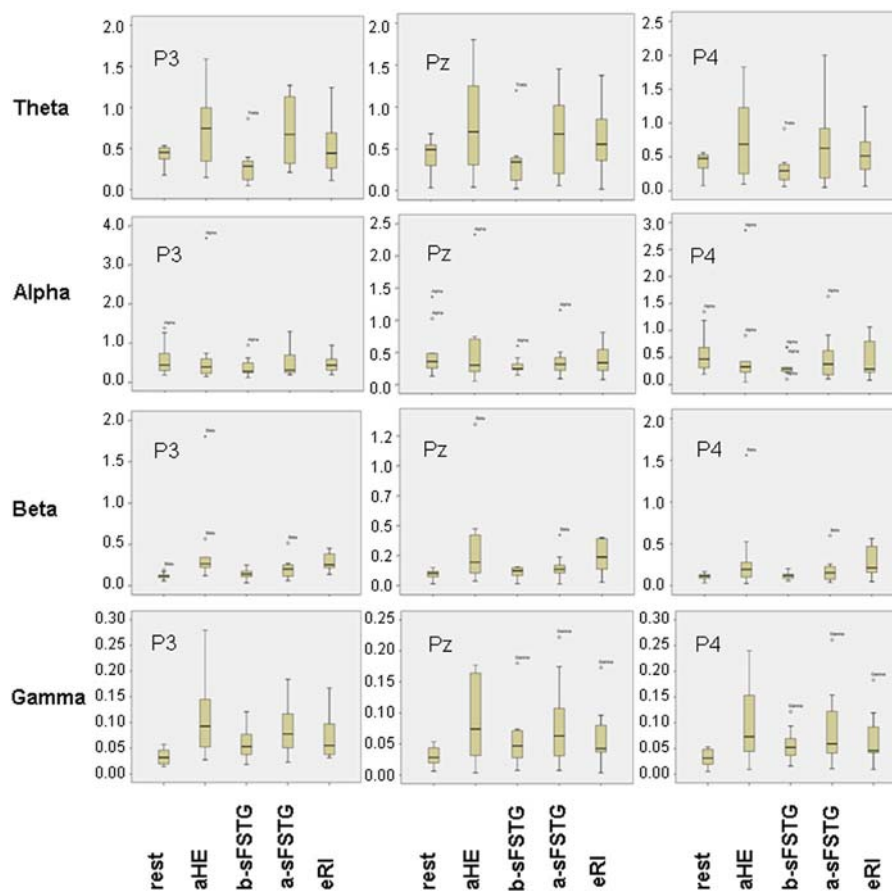


Fig. 2 – Box plots of the mean spectral power (μV^2) of all EEG frequencies during the experimental periods: rest, after haptic exploration (aHE), before spontaneous self-touch gestures (b-sFSTG), after spontaneous self-touch gestures (a-sFSTG), and end of the retention interval (eRI), for the electrodes P3, P4 and Pz.

unpleasant sounds during RI were interfering with the maintenance of the memory load (decrease in theta). In turn, internal contemplation about the fading memory may have led to emotional reactions.

The significant decrease of theta power before sFSTG is contradictory to results showing increases in theta activity in preparation of motor activities. Several studies concerning theta activity during sensorimotor processes established, that theta increases during the planning phase of goal directed movements (Caplan et al., 2003; Cartier et al., 2012; Cruikshank et al., 2012; Tombini et al., 2009; Urbano et al., 1998) and during mental imagery and visualization of sensorimotor planning (Hinterberger et al., 2008). In the cited studies the planned movements were embedded in active decision processes and motor activities. Spontaneous movements like sFSTG are apparently not preceded by a preparatory increase in theta.

3.3. Comparison of 3 s before and 3 s after sFSTG

Furthermore, the spectral power of 3 s before and 3 s after sFSTG were compared. In centro-parietal electrodes we found a significant increase of spectral EEG theta and beta power in the interval after sFSTG (a-sFSTG) (see Fig. 1). No significant changes in alpha and gamma band power were found between these EEG segments. The increase in beta power

above right central regions (C4) after spontaneous self-touch, may represent the activity of motor areas during and after self-touch movements. Several studies have shown that beta activities over central brain regions correspond with motor processes during and after movements (Cassim et al., 2001; Houdayer et al., 2006; Neuper and Pfurtscheller, 1996; Pfurtscheller et al., 1996; Stancak and Pfurtscheller, 1996; Wilson et al., 2010).

The increase in theta power after sFSTG corresponds with results that show that within a range of a few milliseconds during and after movement an increase of cortical theta power occurs in humans (Cruikshank et al., 2012; Kaplan et al., 2012; Rawle et al., 2012; Tombini et al., 2009). However, we did not observe any significant changes in theta activity before and after instructed facial self-touch movements, and for our analyses time intervals of 3 s (pre and post movement) were investigated. Therefore, it is questionable whether the increase in theta power after spontaneous sFSTG reflects post-motor activities.

We assume that the reported changes of spectral EEG theta power in centro-parietal electrodes after sFSTG imply that sFSTG are associated with cortical mechanisms that are relevant for other than for post-movement sensorimotor processes. This conclusion is based on the fact that neocortical theta activity has been shown to be induced by synchronized bursts of a small set of hippocampal

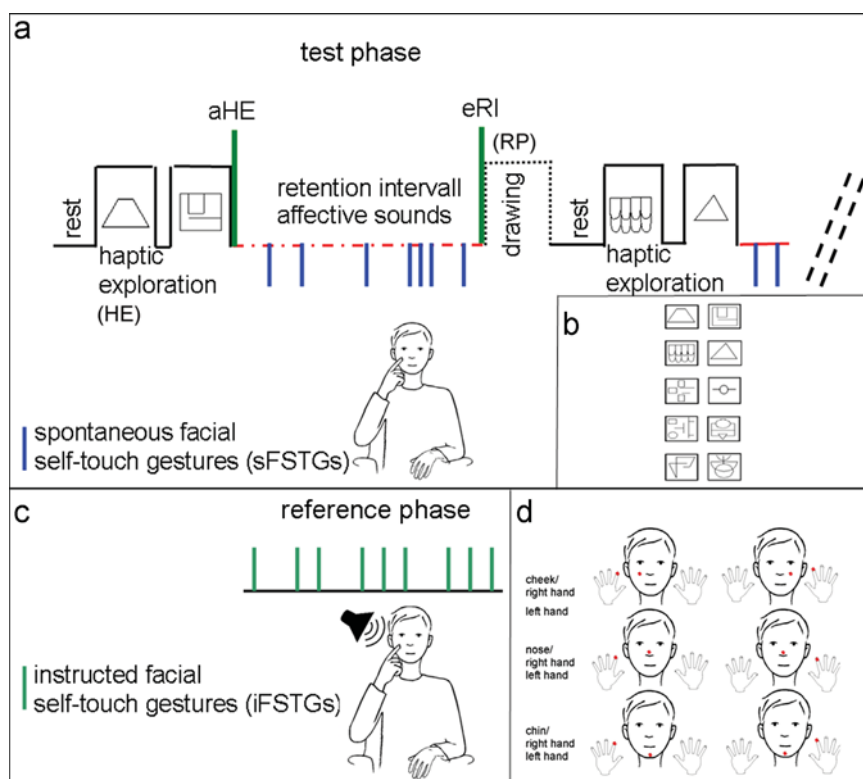


Fig. 3 – (a) Course of the experimental procedure during which spontaneous facial self-touch gestures (sFSTG) occurred: rest, after haptic exploration (aHE), retention interval (RI), end of retention interval (eRI), reproduction period (RP) and (b) schematic graph of the sunken reliefs that were used. Each relief was 13 cm × 13 cm in size. (c) Instructed facial self-touch gestures (iFSTG) during the reference phase and (d) types of instructed facial self-touch gestures.

pyramidal cells in the CA1 field and is regulated by hippocampal-cortical feedback loops (Klimesch et al., 1996; Lopes da Silva, 1992; Miller, 1991; Stewart and Fox, 1990). Hippocampal neurons, as part of the limbic system, are generally involved in working memory, attention, spatial and emotional processes. A loss of these neurons – especially the inhibitory interneurons of the CA1 field (e.g. in patients with Alzheimer's disease or patients with mild cognitive impairment) – leads to deficits in these cognitive abilities. Electrophysiologically, these pathological processes are accompanied by irregularly high theta power (Grunwald et al., 2001a). Results from experimental studies have shown that increases of cortical theta power are related to attention processes (Klimesch et al., 2001; Mitchell et al., 2008), working memory (Fuentemilla et al., 2008; Lundqvist et al., 2011; Mecklinger et al., 1992; Mitchell et al., 2008; Sauseng et al., 2002), emotional processes (Aftanas et al., 2001; Aftanas and Pavlov, 2005; Costa et al., 2006; Krause et al., 2000; Sammler et al., 2007), task switching paradigms (Sauseng et al., 2002, 2006), tasks with goal conflicts (Moore et al., 2006), and when cognitive control is needed to suppress task-irrelevant information (Jensen and Tesche, 2002; Klimesch et al., 1996; Klimesch, 1999; Nigbur et al., 2011; Raghavachari et al., 2001). Some authors are convinced, that theta activity generally regulates executive control during conflict processing (Botvinick et al., 2004; Cavanagh et al., 2009; Luu et al., 2004; Luu and Tucker, 2004). Nigbur et al. (2011) showed an association of

increases in cortical theta power and the acquisition of cognitive control for different types of conflicts in the course of information processing. Sauseng et al. (2007) suggested that variations in theta power are correlates of an attention control system that allocates cognitive resources. Many authors have assumed a close linkage with hippocampal oscillations in the theta band. They suggest that information processing across different brain areas may be integrated by these oscillations (Kahana et al., 2001; Mitchell et al., 2008).

Theta responses to emotional stimuli (auditory, visual) have been investigated in several studies. Basar et al. (2006) found enhanced occipital theta power during the visual presentation of angry faces. Aftanas et al. (2001) showed that spectral theta power increased in parieto-temporal, parietal and occipital areas in response to a sequential presentation of stimuli from the International Affective Picture System (IAPS) with low, medium and high emotional activation impact. These effects were greater for the right hemisphere than the left. 400 ms after stimulus presentation, parietal and parieto-temporal as well as occipital theta enhancement reached its peak. However, 2 s after stimulus presentation the theta power declined almost to baseline level. Krause et al. (2000) found an increase of theta power over occipital electrodes during the presentation of aggressive film contents compared to neutral film contents. Similar effects were shown by Costa et al. (2006) who analyzed EEG activities during the presentation films with neutral, sad, and joyful

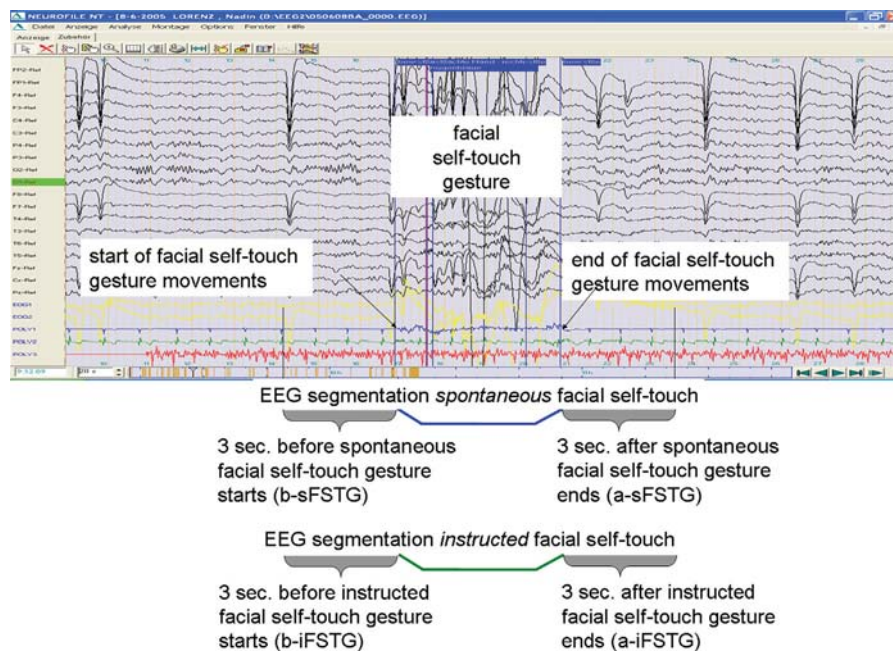


Fig. 4 – EEG segmentation before and after spontaneous self-touch gestures and instructed self-touch gestures. Example of a typical segment with one facial self-touch gesture indicated. EEG (black traces) and EMG of arm movement (blue trace) are displayed.

contents. They found an increase of theta during sad compared to joyful films over frontal electrodes.

Ertl et al. (2013) found that an increase in frontal theta power was positively correlated with the ability of the participants to reduce the emotional reaction to strongly emotional pictures. Therefore, theta activities may reflect active emotional regulation processes as a reaction to emotionally negative external stimuli. Insofar, the decrease in theta activity before sFSTG may represent a critical moment in emotion regulation: loss of emotional control.

We assume, that the parieto-central increase in theta power after spontaneous self-touch gestures represents processes of working memory maintenance as well as a down regulation of negative emotions during sensorimotor integration processes, as postulated by Caplan et al., 2000, 2003; Cruikshank et al., 2012). In this context, theta oscillations “reflect a mechanism for integration more generally, beyond the domain of sensorimotor behaviours, and may serve to coordinate brain activity in a range of tasks for which integration is crucial. This includes learning and memory tasks at one end of the spectrum and sensorimotor tasks at the other” (Cruikshank et al., 2012). The assumption that the theta activity reflects integrative and regulatory functions is also supported by the dynamic changes in theta power over the course of our study. Before the spontaneous facial self touch occurred, the theta power decreased below baseline level (rest). After the self-touch movement it returned to the same level as where it had been after haptic exploration. In line with this, no significant differences were found between a-sFSTG and aHE, as well as between a-sFSTG and the end of the retention interval. Apparently, spontaneous facial self-touch movements lead to a reorganisation or refreshing of the task relevant memory contents. Exactly how this process is organized has not yet been determined. One possible

conjecture may be that a critical decrease in working memory resources – due to interfering and emotionally disturbing external stimuli – is registered internally. To prevent loss of the memory contents and of emotional control, self orientated gestures are initiated. Neurophysiologically, the sensorimotor stimulation of sFSTG may initiate an inhibition of emotional processes and a reactivation of memory contents. The fundamental regulatory mechanisms of these sensorimotor processes should be explored in future studies. In this context, the precise analysis of EEG oscillations during the movement phase of spontaneous self-touch gestures (from the beginning of sFSTG to the end of the movement) with the help of independent component analysis (ICA) techniques may be useful (Lin et al., 2012; Ma et al., 2012; Mammone et al., 2012; Olbrich et al., 2011; Schwartzman and Kranczoch, 2011; Vazquez et al., 2012; Winkler et al., 2011).

Due to the small number of participants, it was logical to limit the number of the analyzed frequency bands to four bands during the present study. Future studies should, however, examine the sub-bands of alpha, beta and gamma as well. Additionally, some findings indicate that slow wave activities of the delta frequency may also be involved with the regulation of cognitive and emotional processes (Knyazev, 2007; Knyazev et al., 2012).

To allow more elaborate analyses of the neurophysiological changes during sFSTG, digital/ electronic markers should be implemented in future studies to facilitate the measurement of the moment and duration of each skin contact during the sFSTG. A precise temporal characterisation of sFSTG would offer a more sophisticated dataset for behavioural as well as future EEG analyses.

Six of the test subjects spontaneously described the experimental conditions as straining. As the results show, the frequency of sFSTG varied between subjects. Which

factors are responsible for this cannot be explained by the present study. In subsequent studies the subjectively experienced amount of strain should be rated by the subjects. These aspects may possibly explain some variance concerning the differences in frequency and duration of sFSTG. Possibly, also gender effects may be associated with sFSTG and certain unpleasant sounds. Future studies should analyze the possible influence of certain acoustic stimuli on sFSTG by using a larger number of participants and an equal number of men and women. A larger number of test subjects would also generate more self-touch gestures which would render the statistical analysis of more EEG epochs possible. Additionally, future studies should investigate the relevance of emotionally neutral and positive auditory stimuli for the occurrence of sFSTG. Various studies have shown that emotionally positive as well as negative auditory stimuli have an impact on working memory processes (Blair et al., 2007; Gyurak et al., 2009; Kensinger and Corkin, 2003; Ochsner and Gross, 2005; Szameitat et al., 2010; Wildgruber et al., 2002)

In our experiment, sFSTG were performed with the fingers of the right as well as the left hand, both in ipsilateral and contralateral face regions. We did not conduct separate analyses for different types of sFSTG—again due to the small number of test subjects but also due to the relatively small amount of sFSTG. Nevertheless, it is possible that neurofunctional differences exist between different types of sFSTG.

Interestingly, the EEG changes observed for sFSTG could not be observed, independently from the memory demand and emotional strain, for instructed facial self-touch (iFSTG; see Fig. 1). This was shown by comparing the spectral EEG power of spontaneous FSTG and instructed FSTG. During the latter no significant changes occurred in the frequency bands under study. Nevertheless, the comparison of both types of gestures is not without problems. Spontaneous behavior (e.g. sFSTG) and deliberately induced behavior can only be compared with reservations. However, we choose this reference situation of instructed facial self-touch gestures to show that the specific EEG changes that occurred during spontaneous FSTG were not simply due to the motor activity. Our conclusion is, that an arousal and/or work-load is necessary for self-touch to have an effect. Due to experimental restrictions, we do not know if instructed self-touch would have presented the same effects on EEG measures as spontaneous self-touch did, during the experimental main part with arousal and work load. Future studies should try to explore and differentiate the effects of spontaneous and instructed self-touch gestures. In the light of modern body oriented therapeutic techniques it might be very interesting to know if self-touch in general (both spontaneous and instructed) has EEG effects.

Both the behavioral and the EEG results of this pilot study support the hypothesis that spontaneous self-touch gestures have a regulatory function. The change dynamics of theta in the course of the experiment indicate that spontaneous facial self-touch gestures substantially serve the regulation of working memory and emotional processes. Possibly, spontaneous facial self-touch gestures and maybe even all spontaneous self touch gestures may also be involved with other perceptual and cognitive processes.

4. Experimental procedures

4.1. Experimental design

The goal of the experimental conditions of our study was to trigger subjects into performing an increased number of sFSTG. During three pre-studies (without EEG) we investigated under which circumstances this would be the case. With the first pre-study we tested if the three test subjects (2 female, 1 male) would show an increase in facial self-touch when listening to unpleasant sounds from the International Affective Digitized Sounds International Affective Digitized Sounds (IADS) (Bradley and Lang, 2000). Compared to an unchallenging quiet situation we could not detect a significant increase in sFSTG.

A second pre-study was conducted (4 test subjects; 2 female, 2 male) to test whether sFSTG would increase during a 5 min retention interval after solving a complex haptic memory task. No significant increase in sFSTG occurred during the retention interval compared to during the haptic task. In a third pre-study we combined all previous aspects: two subjects (both female) had to solve the haptic memory task and were then presented with unpleasant sounds during a 5 min retention interval. We found a significant increase of sFSTG during the retention interval with unpleasant sounds. The design of the study presented below was based on these findings.

Subjects were told that they would participate in an experiment concerning memory effects of haptic exploration. After subjects finished the experiment, the goal of the study was unmasked. The study was approved by the local ethics committee. All subjects gave written informed consent. Subjects were paid for participation (10€/h). Volunteers were seated in a comfortable armchair during the whole experiment. The experiment started with some probe trials during which a sunken relief and examples of sounds (2:38 min with 8 blocks of single sounds) were presented to the subjects. During the following resting phase (baseline) subjects were sitting in a comfortable armchair. Their eyes remained open. Acoustic or haptic stimuli were not present during that time. After rest, the experiment proper started with the haptic exploration task (HE). Subjects were asked to recognize the structure of the reliefs by haptic exploration and were told to remember them since they would have to draw them later. During HE, two sunken reliefs were presented successively (Fig. 3a). The second relief was presented after the subject finished exploring the first relief. The exploration of the sunken reliefs was performed with both hands and open eyes. However, reliefs were obscured from vision by a screen. Subjects were allowed to explore the reliefs as long as they pleased. A schematic graph of the sunken reliefs that were used is displayed in Fig. 3b. The same haptic tasks and procedures have been used as part of other psychophysiological studies (Grunwald et al., 1999, 2001b). As soon as the subjects finished their exploration, the sunken reliefs and the screen were removed. During the following 5 min retention interval (RI), blocks of short sounds were presented via loudspeaker. Forty-four unpleasant sounds from the International Affective Digitized Sounds (IADS) (Bradley and

Lang, 2000) were used (Sound no: 711, 279, 106, 708, 319, 287, 276, 116, 424, 285, 723, 699, 310, 261, 625, 712, 100, 286, 709, 252, 278, 115, 403, 251, 292, 422, 291, 706, 702, 380, 423, 698, 105, 290, 626, 130, 280, 133, 730, 277, 712, 422, 285, 709). As mentioned above, according to our pre-studies, with the combination of the memory task and the disrupting unpleasant sounds, sFSTG should occur at an increased rate during this time.

Subjects' eyes remained open during the retention interval. During the following reproduction period (RP), subjects were to draw the structure of the sunken reliefs on a sheet of paper, to keep up the illusion of a memory task. After RP, the obscuring screen was reinstalled and the next two reliefs were presented. The procedure (HE-RI-RP) was repeated 4 times, to make sure that the occurrence of sFSTG during RI and their possible effect on EEG was not due to chance. The order of the sunken reliefs and of the sounds was randomized between subjects. To test whether the differences in EEG before and after self-touch were due to the induced arousal and work-load we also prompted instructed facial self-touch gestures (iFSTG). At the very end of the experiment, subjects were asked to touch their nose, cheeks, and chin with the left or the right index finger in the sequence shown in Fig. 3d. These instructed FSTG (iFSTG) include the parts of the face most often touched during spontaneous FSTG (sFSTG). Should no differences occur before and after iFSTG, arousal and work load were a necessary condition for FSTG to show an effect. Additionally, mere motor effects could be ruled out. We used this kind of unchallenging reference situation because the instruction to perform facial self-touch during a real test situation with cognitive and emotional load would have prompted internal processes about the role and purpose of the instruction.

4.2. EEG, EMG and video recordings analyses

A 19-channel digital EEG was continuously recorded for all subjects in a Faraday Cage during rest and haptic tasks using Ag–AgCl electrodes at standard electrode positions (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, T6, P3, Pz, P4, O1, O2; reference: linked earlobes; International 10–20 system (Jasper, 1952)). Movements of the right eye were monitored by horizontal (HEOG) and vertical electrodes (VEOG). Electrical impedance was kept below 5 k Ω , sampling rate was 256 Hz. Additionally, electromyogram (EMG) was recorded on separate digital channels of the same recording system (IT-med GmbH, Germany) from electrodes placed on the dorsal sides of both the left and right forearm above m. extensor carpi ulnaris. The recording system allowed for parallel recordings of EEG, EMG, and additionally for the affective sounds and digitized videos of the whole experimental session.

All measurements were carried out in the same lab with the same apparatus under the same conditions at the same time, i.e., between 9 and 12 a.m.

During EEG recordings, different phases of the experiment (start-end rest phase; start-end haptic tasks, start-end retention interval with sound application) and artificial events (e.g. body or head movements) were marked. Off-line analysis included identification of the beginning and the end of all sFSTG. These phases were identified both by video and EMG

recordings. A recording sample of a sFSTG is displayed in Fig. 4. Periods of 3 s (3 artefact free EEG segments with 256 data points) from the time point before the sFSTG started (b-sFSTG) and the time point after sFSTG ended (a-sFSTG) were used to calculate the spectral power. Additionally, for each subject, 80 to 250 artefact-free EEG segments of the first experimental resting period (10 min, eyes open; EEG with 256 data points per segment) were used to analyze the spectral power at baseline. To analyze the spectral power after haptic exploration (aHE), the first 3 artefact-free EEG segments (3 s with 256 data points each), after the subject ceased exploration, were used. Similarly, 3 s off the end of the retention interval (after the affective sounds ceased) were used to measure the artefact-free spectral power of this period (eRI, end of the retention interval).

The experimental setting and the periods used to calculate the EEG spectral power are displayed in Fig. 3a. Analogously, EEG was also analyzed of 3 segments (3 s) before the start and of 3 segments after the end of instructed FSTG (see Fig. 4). This segmentation was paralleled to the segmentation before and after spontaneous FSTG.

Segmentation of EEG data, ocular correction, artefact rejection, and subsequent calculations of the mean spectral power density were performed with an analytical EEG software package (Brain Vision 1.05, Brain Products, Munich, Germany). We used an ocular artefact correction (Gratton et al., 1983) and an automatic artefact rejection with an amplitude criterion of $\pm 80 \mu\text{V}$. Ergo, after automatic artefact rejection, artefact-free segments of 256 sampling points per channel and second were chosen of (a) the resting period [baseline], (b) after haptic exploration [aHE], (c) before spontaneous FSTG [b-sFSTG], before instructed FSTG [b-iFSTG] (d) after spontaneous FSTG [a-sFSTG], after instructed FSTG [a-iFSTG], and of the last seconds of the retention interval (end of sound application) [eRI].

These EEG segments were submitted to a fast Fourier transform analysis. Mean spectral absolute power (μV^2) was calculated as the mean amplitude of the spectral lines of the EEG bands (theta: 4.0–8.0 Hz, alpha: 8.0–13.0 Hz, beta: 13.0–24.0 Hz, gamma: 24.0–49.0 Hz with a resolution of 0.5 Hz, Hanning window, 10%).

The mean spectral power parameters per channel, subject, and experimental phase were used for statistical analysis. For statistical comparisons between spectral power per band and channel non-parametric Wilcoxon tests corrected for α -error accumulation were used. The critical Bonferoni criteria per frequency band was $\text{Alpha}=0.1/11$, $p_{\text{crit.}}=.009$. All statistical analyses were conducted using SPSS for Windows (version 15.0).

4.3. Subjects

Fourteen subjects participated in the experiment. EEG-data of four subjects had to be excluded due to strong artefacts (mainly EMG). Thus, the EEG-data analyses were performed based on whole data sets of 10 subjects (4 male, 6 female; age: $M=26.6$ years, $SD=4.1$). To statistically analyze the amount of facial self-touch gestures during this experiment we used the data sets of all 14 test subjects. All test subjects were right-handed according to a test of handedness (Oldfield, 1971). All

subjects were naïve to any kind of neuropsychological and EEG examinations. This was necessary to ensure that subjects behaved naturally during the retention interval. Test subjects with EEG experience would usually have learned not to move during EEG-measurements. Telling EEG experienced subjects they would be allowed to move would possibly have triggered thoughts about the aim of the experiment and would have destroyed our cover story about studying haptic memory.

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